Overview 2004 of NASA-Stirling Convertor CFD Model Development and Regenerator R&D Efforts

Roy C. Tew[1], Rodger W. Dyson[1], Scott D. Wilson[2], and Rikako Demko[2]

[1]*Thermal Energy Conversion Branch, NASA Glenn Research Center, Mail Stop 301-2, 21000 Brookpark Road, Cleveland, OH 44135-3191, USA*
[2]*Sest, Inc., Middleburg Heights, OH 44135, USA*
[1]*Phone: 216-433-8471, Fax: 216-433-6133, E-mail: Roy.C.Tew@nasa.gov*

Abstract. This paper reports on accomplishments in 2004 in (1) development of Stirling-convertor CFD models at NASA GRC and via a NASA grant, (2) a Stirling regenerator-research effort being conducted via a NASA grant (a follow-on effort to an earlier DOE contract), and (3) a regenerator-microfabrication contract for development of a "next-generation Stirling regenerator." Cleveland State University is the lead organization for all three grant/contractual efforts, with the University of Minnesota and Gedeon Associates as subcontractors. Also, the Stirling Technology Co. and Sunpower, Inc. are both involved in all three efforts, either as funded or unfunded participants. International Mezzo Technologies of Baton Rouge, LA is the regenerator fabricator for the regenerator-microfabrication contract. Results of the efforts in these three areas are summarized.

Overview 2004 of NASA-Stirling Convertor CFD Model Development and Regenerator R&D Efforts

by

Roy Tew and Rodger Dyson, NASA GRC
Scott Wilson and Rikako Demko, Sest Inc.
All Work in Thermal Energy Conversion Branch at GRC

Presented by Roy Tew and Rodger Dyson

for
STAIF 2005
February 16 or 17, 2005
Albuquerque, NM

Outline

- Roy Tew
  - Overview of Adv. Stirling Tech. CFD Modeling & Regenerator R&D
  - Multi-D Code Grant
  - Regenerator Research Grant
  - NRA Regenerator Microfabrication Contract

- Rodger Dyson
  - Draft Long-Range GRC Stirling-Computational-Analysis Plan
  - Recent Fluent Stirling Engine Multi-D Simulation Results

Overview of Adv.-Stirling CFD Modeling and Regenerator R&D

- At GRC, CFD-ACE & Fluent Models of STC's TDC Developed
  - Goal: Learn More about Engine Losses & Enable Improved Design
- Anticipate Modeling Sunpower Engine(s) (Buzz-35 W, Other?)
- CFD Problems:
  - Computation Speed (Solutions: Clusters, Adv. Num. Tech.--Dyson)
  - Need Non-Equilibrium Porous Media (Regen.) Models
    - Several Such Models Identified
    - Initial Empirical Coefficients (Closure Models) Determined
  - Turb. Modeling? – Laminar or Particular Turb. Model Everywhere
    - Lam. & Turb. Flow in Different Engine Regions at Same Time
    - RANS Turb. Models Avail. – Can't Reliably Predict Lam. Flow
    - LES in CFD-ACE & Fluent, DES in Fluent--but Time Intensive
  - Transient Conjugate-Heat-Transfer Problem

Stirling Multi-D Code Grant

(CSU, UMN, Gedeon Assoc with STC & Sunpower as Unfunded Participants)

- *Earlier Grant*--CSU Developed Initial 2D CFD-ACE Engine Model & Solid Temp. Accel. Approach—Transmitted to GRC—That Got GRC Started

- UMN Developed 90 Deg. Turn Test Rig—To Roughly Model Expansion Space Fluid Flow—CSU Modeled the Rig, Tried Various Turbulence Models—Test Data Available in Reports for Others to Use

- *Latest Grant*--UMN Recently Dev. 180 Deg. Turn Test Rig—Improved Model of Expansion Space Fluid Flow & Heat Transfer—Testing to Begin Soon—CSU will Develop CFD Model of Rig

- CSU Developed Stirling Cooler Test Module for SLRE—Pressure, Pressure Drop Data Taken—3-D Fluent Model of Test Rig under Development—Temperature Measurements to be Taken (?)

UMN "180 Degree Turn" & CSU SLRE Cooler Test Modules

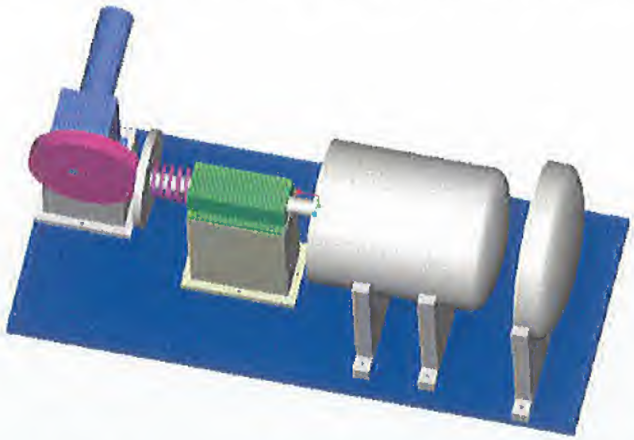


FIGURE 3. New Oscillating-Flow Generator and 180 Degree Test Section.

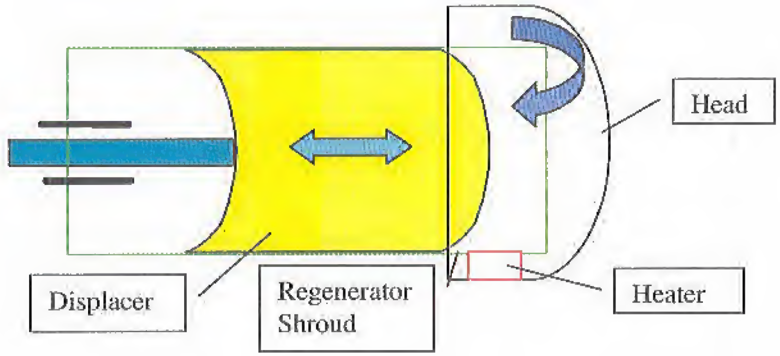


FIGURE 4. Schematic of New 180 Degree Test Section.

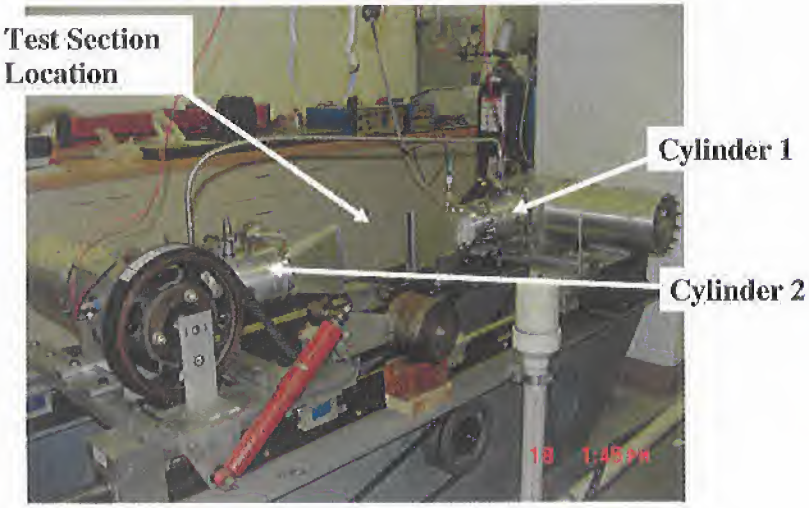


FIGURE 5. SLRE with "Alpha" Arrangement of 2 Cylinders/Pistons, Showing Test Section.

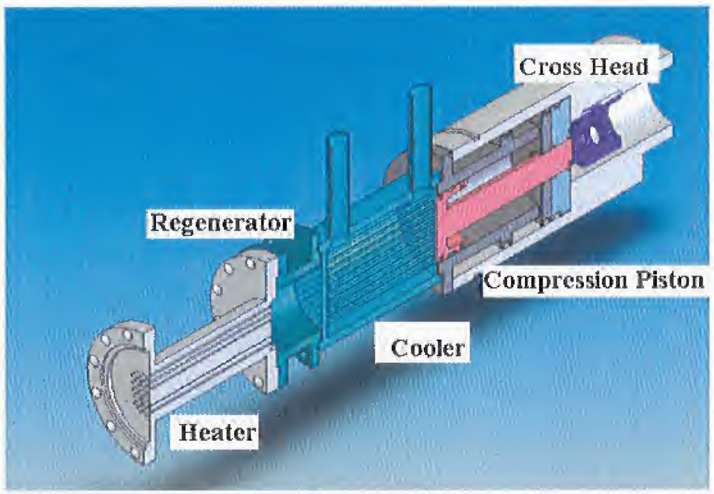


FIGURE 6. New SLRE Stirling Cooler Test Section.

Regenerator Research Grant

(CSU, UMN, Gedeon Assoc., Sunpower—Follow On to 3 Year DOE Contract)

- UMN Large-Scale Regenerator Test Rig—For Studying Regenerator Flow & Heat Transfer—90% Porosity Measurements almost Complete, 95% Measurements To Be Done—Initial Study of Cooler Tube Jetting Into Matrix Complete, Several Other Exit Geometries To Be Studied—Determined Permeability, Inertial Coefficient & Thermal Dispersion for Use in CFD Porous Media Model

- CSU CFD Modeling of UMN Test Rig—Also Calculating via CFD Model, Permeability, Inertial Coefficient and Thermal Dispersion

- Sunpower Oscillating-Flow Test Rig—Take Friction-Factor and Heat Transfer Data for Range of Random Fiber Matrices to 95% Porosity—Test for Effect of Fabrication Variability

- Mitchell/Stirling Etched-Foil Regenerators—Fabrication Estimated to be Complete Feb. 2005—To Be Tested In Sunpower Oscillating-Flow Rig

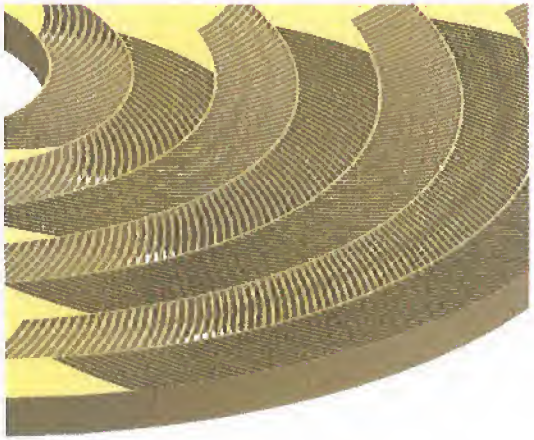
NRA Regenerator Microfabrication Contract

(CSU, UMN, Gedeon Associates, STC, Sunpower & International Mezzo Tech.)

- 1st year Complete, 2nd Year Awarded—Started Nov. 17, 2004
- Microfabricated "Defined Geometry" (Not Random) Chosen to Reduce Pressure Drop (Next Slide)
- International Mezzo Technologies Chosen During 1st Year—To Fabricate With Combination of LIGA (Lithography, Electroplating & Molding) & EDM (Electric Discharge Machining)
- UMN Developing a Large-Scale Model of the Microfabricated Regenerator to Support the Effort
- David Gedeon used Sage 1-D Code to Project Potential 6-9% Performance Improvements for Sunpower ASC Engine, Over Random Fiber Regen.

NRA Microfabricated Regenerator

Solid Model



- 86 micron channels
- 14 micron walls
- 1 mm ring spacing
- 0.5 mm thick

FIGURE 7. Chosen Involute Concept.

Stirling Engine Nickel Electrode

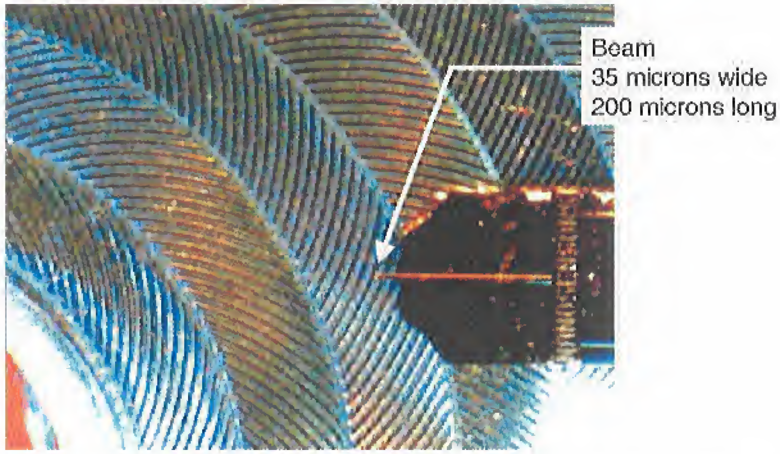


FIGURE 8. Mezzo EDM Tool, fabricated via LIGA.

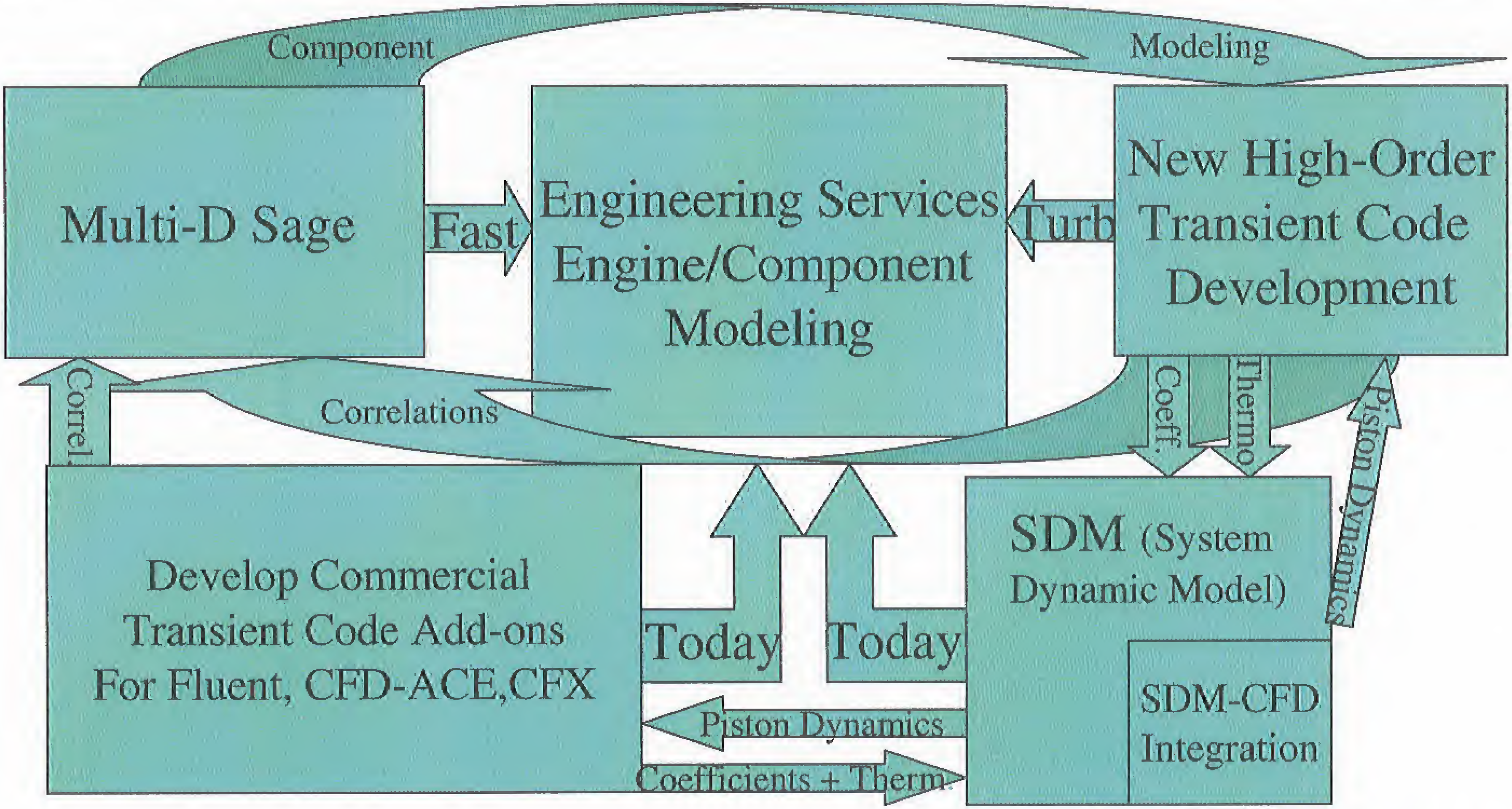
Stirling Simulation for Space Exploration

The following slides suggest a roadmap for the development of analysis tools for impacting Stirling engine design. This is not a complete business plan but only serves to make broad connections between what needs to be done and how to get there.

There are 5 product areas that our advanced Stirling analysis group could contribute to and they are briefly described in what follows. Notice how the areas relate to one another and all feed into the goal of impacting engine design in different ways.

Stirling Analysis Proposed Products (DRAFT)

Goal: Provide tools and analyses to allow further improvements of Stirling convertor performance



Engineering Services

- Provide analysis for testing/experiments
  - Waterjacket, Insulation Jacket, etc.
- Improve designs for next generation Stirling configurations
  - RPS.High power, Very small, Complex geometry, ...
- Identify improvements on current designs
  - Identify losses, Enhance efficiency
- All other efforts feed into this
- Project duration: ongoing

Upgrading Sage, or Similar Steady-Periodic Code

- Extend Sage, or similar steady-periodic code, to 2D and 3D
- Utilize high-order discretization in space and time
- Important for multi-dimensional fast design speed solutions
- May not properly model turbulence, instabilities
- Provides boundary conditions for component modeling
- Challenging research project—Journal publications
- Project duration – 3 years

Upgrade Commercial Transient Codes

- Upgrade Fluent/CFD-ACE with better porous media models, turbulence, transition modeling and if possible, improved conjugate heat transfer convergence
- Validate Fluent/CFD-ACE Stirling models
- Utilize current packages to provide immediate Engineering Services where practical
- Include fluid-structure interaction (FSI) and electromagnetic (EM) system analysis
- Can provide improved correlations for Sage
- Can provide gas spring and other coefficients for current SDM effort
- Project Duration - 3 years

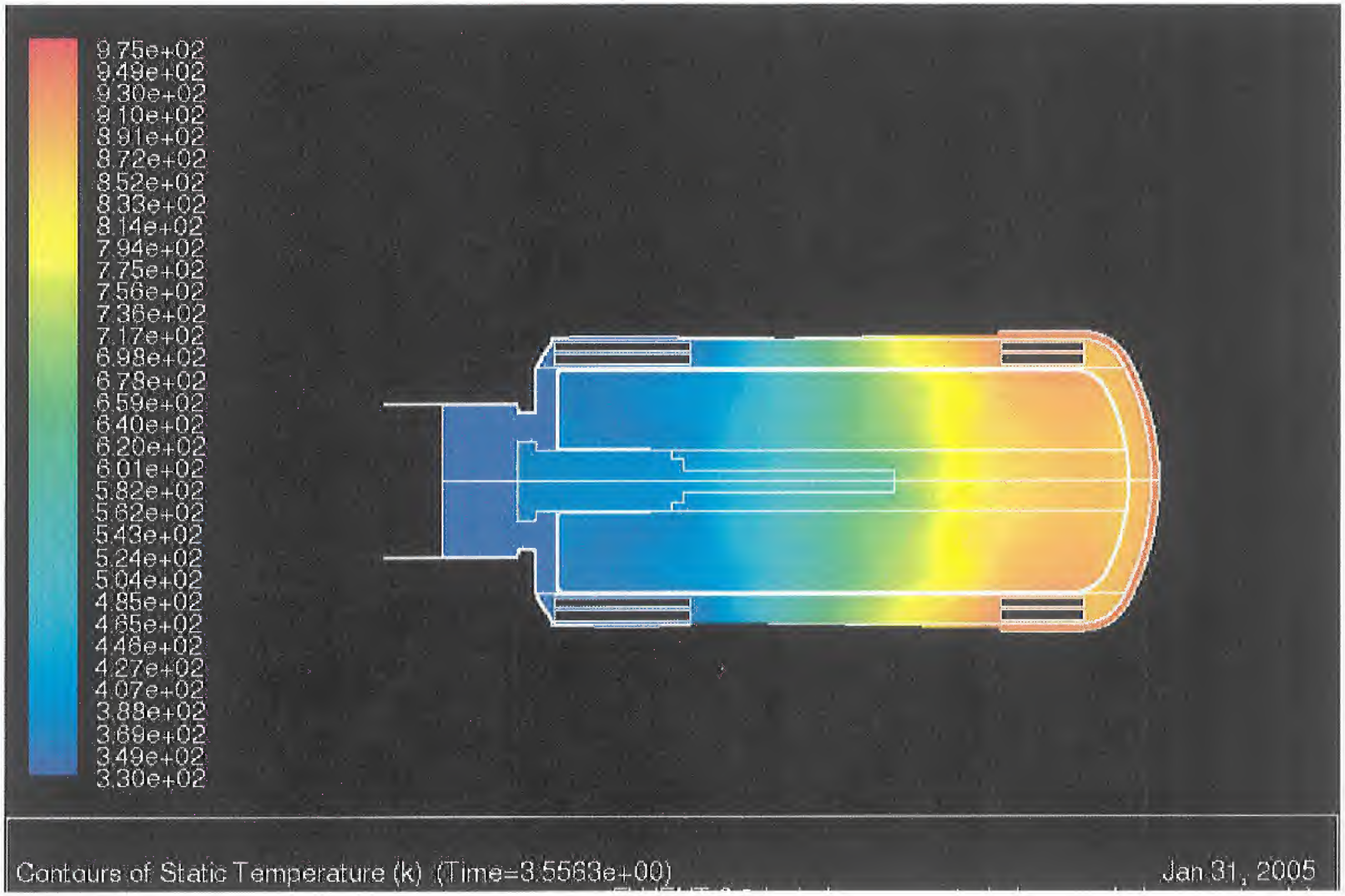
New High-Order Transient Code Development

- Develop new high-order transient code to resolve entropy features/identify losses (low order codes too diffusive in some cases, i.e. boundary layers)
- Incorporate 1D transient code into current SDM (supplements Sage's steady harmonic capability)
- Develop 2D and 3D high order transient code to study turbulence, instabilities, and other a-periodic flow features
- Provides improved correlations for Sage
- Project Duration: 3 years

Integrated SDM-CFD Code (long-term)

- Perform system dynamic modeling with Computational Fluid Dynamics, FSI and lumped parameter EM system analysis
- Current SDM and CFD efforts have related goals in a very broad sense, but different emphasis (broad and low information density VS. focused and high information density).
- SDM can provide piston dynamics (phase angle/amplitude) for CFD
- Coefficients for current SDM can be found with CFD
- Develop an SDM model utilizing parallel Mathematica for faster solution with more detail
- Utilize new 1D transient code in current SDM model instead of Sage steady-periodic code for truly transient analysis
- Project Duration - Ongoing

Fast Whole Stirling Engine Simulations



Concluding Remarks

- Multi-D code grant produced initial CFD Stirling model & is providing CFD code validation data
- Regenerator research grant has provided new regenerator insights, data for regenerator code validation, & will provide new high-porosity regenerator correlations for 1-D codes
- NRA regen. microfab. contract is building prototype of new microfab. regen. for improved Stirling perf.
- GRC Stirling Multi-D code development is moving in-house to GRC
- However, NASA will continue to need advanced Stirling technology grant & contractual support in areas of CFD validation testing, regenerator testing, and in development of improved CFD techniques

ACKNOWLEDGMENTS

The work described in this paper was performed for NASA Headquarters, Science Mission Directorate (Code S) and Exploration Systems Mission Directorate (Code T). Any opinions, findings, and conclusions or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the National Aeronautics and Space Administration.